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THE WILMINGTON (N. C.) WATER SUPPLY.

AN INVESTIGATION MADE DURING NOVEMBER AND DECEMBER, 1913.

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The investigations reported herewith were made by the writer under instructions from the Surgeon General of the United States Public Health Service. The work was done in response to requests received from the secretary of the State Board of Health of North Carolina and from the mayor of the city of Wilmington.

To supplement the information derived from personal interviews and from charts, maps, and data previously collected by others and referred to at the end of this report, a careful inspection has been made of the city waterworks and waters of both branches of the Cape Fear River in front of the city and up to points that are well above the effect of pollution from the city. The location of sewer outlets existing at present and as contemplated in the future extension of the sewer system and plans of the projected system have been given careful study. Samples of water from the present waterworks intake and from both branches of the river at points above the effect of Wilmington's pollution have been taken and submitted to special study, and some specimens of these waters have been sent to the Washington Laboratory for more detailed study.

From the information that has been derived from all these sources the following statement of facts and of opinion derivable from these facts is presented.

The Present Water Supply.

THE CAPE FEAR RIVER.

The Cape Fear River proper is formed by the junction at the city of Wilmington of two branches known, respectively, as the Northeast and Northwest Branch of the Cape Fear River. The Northeast Branch has a comparatively flat grade and drains a portion of country which is characterized by low swamp land, so that a large proportion of the run-off of the stream is a characteristic swamp water. The stream is therefore characterized by a high color and organic stain and apparent freedom from suspended matter or turbidity. The water is soft and faintly alkaline in reaction and except for the undesirable appearance of such a highly colored water it is admirably adapted for domestic uses. The Northwest Branch, on the other hand, drains a region characterized by rolling country and hills, and its run-off is largely composed of surface waters carrying with them the usual heavy turbidity and sediment common to southern rivers. It is almost free from organic coloring matter and is also relatively soft, so that except for the unsightly appearance and general undesirability of the suspended mineral matter it also would constitute an ideal domestic supply.

POLLUTION.

The present waterworks intake is located on the Northeast Branch, about 1 mile above the junction of the two branches and about 1½ miles above the center of population of the city. The sewers of the city discharge into the river at various points along the water front and a considerable portion of the eastern section of the city drains by sewers to a tributary of Smiths Creek, which latter enters the Northeast Branch at a point shortly above the present waterworks intake.

Tidal currents attain a maximum velocity of approximately 1 mile per hour and run to the north for five hours on each flood tide. A careful study of the best available data on this question leads to the conclusion that some of the water which passes the present intake during the flood tide has come from a point at least 3 miles below, so that there can be little question that the Wilmington water supply is definitely polluted by the sewage of the city. On the ebb the polluted waters of Smiths Creek flow by the intake. The dilution of polluting matter, however, is very great, owing in part to the large volume of the Northwest Branch. A distinct improvement in conditions will also follow the removal of the sewage from Smiths Creek by the interceptor which has just been completed and from which sewage will be pumped over the ridge and discharged at a point south of the intake.

Bacteriological examinations of the raw water at the intake furnish evidences of the degree of dilution available. The average bacteriological content of the raw water for two years has been about 2,500 bacteria per cubic centimeter and the organism *B. coli* has been fairly consistently present in 1 cubic centimeter. Judged by ordinary standards for river waters this pollution is not serious. Many cities of the United States, such as Lawrence, Mass., Albany, N. Y., and Philadelphia, Pa., are purifying waters that are more grossly polluted. It should be pointed out, however, that the pollution in the present instance is exceedingly fresh and that bacterial evidences of such pollution has a much greater significance in these circumstances than it has in a stream that has a much greater period of self-purification. It is known that pathogenic organisms do not persist as long under the average conditions found in streams as do the normal sewage bacteria. It is therefore evident that the longer the time that has elapsed between the point of pollution and point of intake the less significant the ordinary bacterial evidence of pollution. On the whole, however, it may be safely asserted that the water of the East Branch of the Cape Fear River, although distinctly polluted by the sewage of Wilmington, is a suitable water for purification and is undoubtedly superior to waters that are in use by many cities throughout the United States.

PURIFICATION PLANT.

The water supply pumped from the east branch of the Cape Fear River is purified by what is known as the process of mechanical filtration. For this purpose sulphate of aluminum and carbonate of sodium are added to the water which is then passed through sedimentation basins. The precipitated hydrate of aluminum has the property of gathering together all finely divided suspended material, including the bacteria, and also of absorbing in part the dissolved color of the water. For the complete removal of such color either a considerable amount of alumina must be provided or a long time of contact—at least 24 hours—is necessary. After this chemical treatment the water is passed through filters which remove any portion of the aluminum hydrate that passed the sedimentation basins giving, under ordinary working conditions, a water that is essentially free from bacteria and from other suspended material and has been deprived of a considerable proportion of its color.

The Wilmington plant is being operated under conditions which do not make for best results. At the time of its original design the difficulty of treating such a highly colored water was probably not fully realized, and those responsible for additions to the plant have not taken advantage of our increased knowledge in this subject. In order to deal efficiently and economically with a water of this character, a longer period of contact with the coagulant is quite essential. At the present average rate of pumping of something over 2,000,000 gallons per day the water will pass either set of coagulating basins in about 4 hours. As the rate of pumping is very much increased during the day and correspondingly cut down during the night, the majority of water used passes through the tanks in a much shorter period. The velocities through these tanks are too great to permit proper sedimentation and the time of contact with the coagulant is entirely too brief. The changes which are now under way will permit the use of both sets of tanks in series and will double the time of contact but will not increase the time of passing. A distinct improvement will follow this change, but if possible the pumping connection should be so arranged that the two sets of tanks can be used in parallel, each taking one-half of the total amount of water, thus diminishing the velocity and permitting better sedimentation.

The filters themselves are said to have been allowed to deteriorate during the summer, but they have now been provided with new sand and are apparently giving satisfactory results. It is probably true, although definite information upon this point is lacking, that an excessive amount of wash water is being used. It is impossible to measure the amount of wash water used, and this conclusion is based upon the appearance of an excessive amount of coagulant passing to the filters from the sedimentation basins. It is highly desirable that means be provided for measuring the amount of wash water used and especially for measuring the total amount of water pumped. In no other way can the application of chemicals be properly adjusted.

CHLORINATION.

The work of the filters is supplemented by the application of chlorine gas, a powerful disinfectant. The apparatus that has been installed is a modern and thoroughly satisfactory one and when properly operated should leave no possible question of the hygienic quality of the water. During the summer this apparatus was insufficient in capacity to care for the total quantity of water pumped. This defect was remedied and satisfactory results followed immediately.

CHARACTER OF THE PURIFIED WATER.

Samples of the purified water are sent to the State laboratory once each month and a daily test is made at the plant by the director of the laboratory. During the first half year of 1911 the regular examinations of samples taken at the filter indicated the absence of *B. coli,* the test organism for pollution, although the general bacterial content of the water was not highly satisfactory. Some special samples collected on May 30 and 31 and June 1 and 2 showed *B. coli* present in all cases and in the majority of cases in 1 cubic centimeter. The fact is to be noted, however, that these samples were taken from various taps in the city and it has been stated that at the time a considerable amount of new water pipes had just been installed. This statement has not been further investigated, but may explain in part the results obtained. After July, 1911, and until May, 1913, the bacterial results reported from the State laboratory were satisfactory, *B. coli* being uniformly absent from 10 cubic centimeter quantities. The results obtained at the plant are in conformity with those obtained at the State laboratory. *B. coli* appeared in 10 cubic centimeters in May, 1913, and the water gradually deteriorated during that summer, as shown by both local and State analyses. The reasons for this deterioration have already been alluded to. The imperfections have now been remedied and recent analyses indicate the satisfactory operation of the plant and a safe water. The chemist and bacteriologist in charge of the sanitary operation of the plant is a competent man and if he is given proper support there is no reason why the present purification works should not be relied upon to produce a thoroughly safe and satisfactory water.

OBJECTIONS TO THE PRESENT WATER SUPPLY.

Despite the assurances that have just been given, there are certain objections to a water supply of this character which should have weight in any discussion of the whole water-supply question.

Danger of infection.—A filter plant, however perfect, is never an absolute guaranty of protection against a polluted water supply In Lawrence, Mass., in 1899, a rather serious outbreak of typhoid fever resulted from the accidental failure of the water plant, and at Watertown, Me., Philadelphia, and other places serious results have followed similar breakdowns. It can not be denied that the use of a polluted water is always attended with a certain moment of danger, and every effort should be put forth to secure as pure a water supply as is reasonable and feasible.

Esthetic objection.—A modern water filter can produce under normal conditions of operation a water that is perfect from a hygienic standpoint; still there is a perfectly reasonable objection on the part of many to the use of a water with a known history of pollution. However unreasonable such views may appear to those who believe otherwise, they may be of real importance in the general discussion of the problem. In the first place, such esthetic objections, whether or not they are well founded, lead naturally to the use of other waters, and in many cases to waters of far less hygienic purity than the city supply. It may be further urged that the objectors have a reasonable right to be consulted as to the quality of water that they shall pay for, and that due weight shall be given to their opinions and desires. There seems to be a very strong feeling against the water supply of Wilmington in this regard. This feeling is freely and forcibly expressed, and it is a matter which is likely to increase rather than decrease. It at least furnishes an additional and strong argument for a water supply of greater initial purity, quite regardless of the filter plant, to render the city water perfectly satisfactory.

Use of aluminum sulphate.—A third and quite serious objection to the present supply is the rather large quantity of sulphate of aluminum that is necessary. While under proper conditions this compound is entirely changed in the coagulating basin and the aluminum hydrate is completely removed, either in the basin or upon the filter, there does result from the application of the two coagulating chemicals a perfectly harmless substance in the water which increases its corrosive properties. This increase of salinity is responsible for the rapid deterioration of lead and copper flush tanks and other metal fixtures, many instances of which have been reported and commented upon. It is also responsible to a considerable degree for the rusty water that is commonly encountered, especially in the hot-water services.

SUMMARY ON PRESENT SUPPLY.

In brief summary it may be stated that the present water supply comes from a moderately polluted source, but can under normal working conditions be rendered perfectly safe and satisfactory from a hygienic standpoint. There is, however, a slight danger of failure on the part of some of the purification mechanism and it is obvious that the plant must be run at all times at its highest possible efficiency and under intelligent and harmonious cooperation among those in authority. There is in addition a considerable amount of organic stain which is difficult to remove and which requires the application of more sulphate of aluminum than would otherwise be called for. On these accounts it is desirable to consider the feasibility of other sources of supply, giving due weight to their respective cost and the amount and quality of water which may reasonably be expected of each.

Deep Wells.

GENERAL DISCUSSION.

The deep-well situation in Wilmington and general vicinity has been rather thoroughly investigated. There appear to be several underlying water-bearing strata. Near the surface there is the surface water such as is found in shallow wells and which requires no further consideration. At depths varying from 100 to 300 feet there exists the Eocene limestone formation within and beneath which there seems to be an available supply of water. The Report of the North Carolina Geological and Economic Survey, Volume III, 1912, prepared by Joseph Hyde Pratt, State geologist, in collaboration with workers from the United States Geological Survey, describes in some detail the underground formation in the vicinity of Wilmington and gives valuable information on the subject of deep ground waters. The matter has also been treated quite extensively by Myron L. Fuller, at that time geologist of the United States Geological Survey, in a paper presented before the American Water Works Association in 1908. It appears that the water-bearing strata of the Coastal Plain region slope gently from the basement granite outcrop which traverses the State in a northeasterly line from the region of Anson County on the south to Warren County on the north. These water-bearing strata, which outcrop at various distances to the southeast of the granite formation, slope toward the sea, so that in the vicinity of Wilmington the Eocene limestone and underlying calcareous sand, all of which are water bearing, are located from 100 to 300 feet below the surface. The water which they bear comes originally from the rainfall on the catchment areas to the east of the granitic outcrop alluded to.

QUANTITY OF WATER AVAILABLE.

The reports alluded to indicate in general an abundant supply of ground waters in the Eocene formation. It is further evident, however, that this formation is irregular and is often encountered at isolated patches, so that the available catchment area in any given case is a somewhat uncertain factor.

The personal experience of Mr. W. E. Worth is of interest in this connection. A new well put down within 200 feet of a well which was giving a copious supply failed to tap water-bearing strata.

In a personal letter addressed to the city chemist, Mr. Pratt, State geologist, states:

> Those strata that are reached by wells 100 to 300 feet deep offer the possibility of a water supply. These wells may not be in the immediate vicinity of Wilmington, but may be some distance from it. I do not believe that anyone can state definitely at the present time whether or not water in sufficient quantity can be obtained from such wells to supply the city of Wilmington, not only for the present but for the next 20 years.

Mr. Pratt further shows his lack of confidence in the possibilities of deep wells by suggesting that if a pure-water supply can not be obtained from other sources the question of deep wells should be considered.

So far as I have been able to obtain the facts concerning certain wells that are now in use in Wilmington, there seems to have been no difficulty except in the one case alluded to in obtaining wells with an abundant supply for private use.

SANITARY CHARACTERISTICS.

Out of 70 examinations made by the State board of health of the water of deep wells in Wilmington, 17, or approximately 24 per cent, gave definite evidence of pollution. It is true that this evidence is not of great weight since it may very possibly represent imperfect casing or some accidental pollution, but in certain cases even this explanation fails to account for the facts. This is especially true in the case of a well put down by the Wilmington Ice & Storage Co. at Front and Dock Streets. This well gave a satisfactory analysis at the time it was put down, but on continued pumping developed marked traces of pollution together with an excess salinity which has precluded its use.

The question of hygienic purity of well waters is, therefore, somewhat indefinite. It seems quite probable that these waters tap limestone beds in which are contained definite open channels and cavities of various sizes largely intercommunicating. Evidence of this view is the effect of new borings in increasing the turbidity of wells at quite distant points. It is not at all unlikely that these waters are also in communication at certain places with the waters of the upper strata and that continued use on a large scale of these deep-well waters would lead to a gradually increasing pollution. This, however, is merely conjecture, and it can only be stated at this time that data upon which to base any definite conclusion of the permanent sanitary purity of the deep-well waters from this region are entirely lacking and can not of course be obtained by any means less expensive than the actual installation and long-continued trial of deep wells operated under the severe conditions of municipal service.

CHEMICAL CHARACTERISTICS.

These well waters are also high in alkalinity, or, as it is commonly called, temporary hardness. The analyses that are available show alkalinities ranging from 75 to 250 parts per million. While this degree of alkalinity has no hygienic significance, it is a distinctly undesirable characteristic in a water for domestic use, and upon a purely esthetic basis is certainly less desirable than the slight amount of organic color which remains in the present water after purification. The household use of such waters would result in a very material expense each year from excess soap requirement, and the people of Wilmington, being accustomed to the use of an extremely soft water, would without doubt raise very pertinent objection to a water having several times the hardness of the Washington City supply, doubtless familiar to many of them.

Industrially, alkalinity is a much more serious matter, and well waters of the character of those which have been examined would be quite useless for boiler purposes or for industrial laundries. The case of one local laundry was brought to my attention. It is stated that an attempt to use a deep-well supply was abandoned owing to the excessive amount of soap required.

The amount of iron noted in certain of the analyses reported by the State geological survey suggests the possibility of another serious impurity which should not be overlooked. An excessively high iron content is highly undesirable and in many places necessitates expensive purification methods.

SUMMARY ON WELL PROJECT.

The deep-well project is seen to be characterized mainly by lack of definite information. There is a distinct element of doubt as to the possibility of securing a sufficient supply that will continue year after year. There is even more serious doubt as to the hygienic quality of the water thus obtained. Even though pure water may be obtained under conditions of moderate draft it is not at all certain that the severe duty entailed by the necessities of a municipal supply will not develop communicating channels with the polluted waters of the upper strata. The facts that are definitely known are all against the deep-well supply. The water would be exceedingly hard, highly undesirable for domestic use on account of its excessive soap consumption and great inconvenience associated with the use of a hard water, and it would be totally unfit for laundry and industrial uses. On the whole, therefore, the deep-well project is one which may be well held in reserve until all other possibilities have been properly investigated and shown to be even less favorable.

Alternative Projects.

Fortunately the city of Wilmington is not compelled to make the experiment in deep wells at this time. The present situation is not at all intolerable, and with careful management the demand for immediate relief is not great. There are certain methods which may be properly investigated with a view to overcoming the more serious objections to the present supply which have been discussed under the headings, "Danger of infection, esthetic objections, and use of sulphate of aluminum." The removal of the present intake to some more satisfactory location naturally suggests itself.

NEW INTAKE ON THE NORTHEAST BRANCH.

It has been suggested that the intake might with advantage be located at a point considerably upstream on the Northeast Branch. It would not be difficult to find such a point where immediate pollution from the sewage of the city would be entirely eliminated. This would bring partial relief from two of the objections noted. There would be no danger from pollution and the esthetic objection against the use of a water showing a history of pollution would be removed. It should be pointed out, however, that the water supply is to a considerable extent a mixture of both branches of the river. Samples taken from the Northeast Branch above the influence of the Northwest Branch and also of the city's sewage showed a much deeper color than the present city supply. The difficulties of color removal would be very much greater at this point and the final product of the filter would necessarily be more highly colored than is the present supply.

Only by increasing the dosage of aluminum sulphate could this difficulty be obviated. The objection to the use of a coagulant would then be greater than at present. It has also been suggested to cross the country with an intake line to a point above the town of Castle Hayne. This project offers no apparent advantages over the removal of the intake 3 or 4 miles upstream and has all the disadvantages that have been pointed out.

NEW INTAKE ON THE NORTHWEST BRANCH.

It has already been shown that the waters of the Northwest Branch are very different in general characteristics from those that are now being used. The principal branch of this stream comes from mountainous country. There is one tributary, the South River, draining low land and undoubtedly contributing some of the color to the water. The normal clay turbidity carried by the Northwest Branch counteracts this color, and samples from this river shipped to Washington show a color less than one-tenth that shown by the Northeast Branch. An intake force main, running directly across from the present pumping station, following the railroad right of way, would tap a small branch canal at a distance of about 2 miles from the pumping station. This canal enters the Northwest Branch at a point 4 miles above Point Peter, and the upper end of the canal again joins the river at a point 7 miles above Point Peter. With a tidal flow reaching a maximum of 1 mile per hour and running up for five hours during each tide, little, if any, of the waters from below Point Peter would ever reach the lower end of this canal. Moreover, it would be an exceedingly simple matter to provide this canal with tidal gates, so that the flood flow could be entirely eliminated. In this way the water received at the intake would come from the Northwest Branch well above any possibility of pollution. The long sluggish canal would also serve as an efficient sedimentation basin and would greatly relieve the work of the filter.

A small pumping station, electrically operated and controlled from the main pumping station, could easily be maintained at the end of the intake line. This line could be laid along the surface of the ground, preferably along the railroad right of way, at a very small cost. The only expensive feature of the project is a siphon under the Northeast Branch. The channel at this point, however, is constricted by the drawbridge, and the deep portion of the siphon would be greatly shortened.

ADVANTAGES OF THIS NORTHWEST BRANCH PROJECT.

This project meets quite satisfactorily all the objections that have been urged against the present supply. It removes, totally, the hygienic and esthetic objections to a polluted water, and experience with waters of a similar type that are being treated elsewhere, coupled with laboratory investigations that have been made in Washington upon samples of this water, indicate that the dosage of aluminum sulphate required for its proper treatment would be less than one-half that now employed. This would reduce to a negligible minimum the corrosive properties of the water that are now observed.

In the matter of cost this project is probably the most economical one in the long run that has been suggested. It will probably be shown upon further study that the saving in chemical will offset to a large extent, if not entirely, the additional capital charge. The project offers the advantage of utilizing all the existing works and represents a merely normal growth of the present water-supply system rather than a complete abandonment of a large and expensive portion of that system. This growth is in the line of progress and is in the direction taken by many other cities that have from time to time abandoned deep-well projects to seek a pure river supply.

Finally it is a project that is capable of exact engineering studies and that can be undertaken with a full knowledge of the exact cost and exact advantages to be obtained. It offers, even with our present incomplete knowledge, evidence of an abundant supply that will undoubtedly remain pure for a very long time in the future, and one whose purification involves no uncertain or difficult methods.

Conclusions and Recommendations.

As a result of a careful study of the present water supply of Wilmington and the possibilities of a deep-well supply and of other river supplies, the deep-well project has been found to involve many elements of uncertainty and to be definitely lacking in that it would supply an undesirably hard water and the continued use of the river water is strongly recommended.

The present water supply as it is now operated is, on the whole, quite satisfactory. Every effort should be made to maintain the purification plant at the highest possible degree of efficiency, and to this end certain changes seem imperatively necessary. The suggestion of communicating channels between the old and new sets of filters made by the chief engineer, Mr. John H. Sweeney, is an excellent one and should be adopted. This will make it possible to utilize for the first time the entire filter capacity of the plant. The connections which are being made between the two sets of settling basins will also prove of great benefit. It would be still more advantageous if piping connections with the pumps could be so arranged that these two sets of basins could be used in parallel as well as in tandem. This would not only give the maximum time for coagulation, but would allow the minimum horizontal velocity of flow through each basin, thus permitting the most efficient sedimentation of coagulant and permitting saving in wash water. The force main and wash water lines should be equipped with properly constructed Venturi meters. It is impossible to properly control the operation of a plant of this type without definite knowledge at all times of the amount of water being used. The meters on the wash lines constitute invaluable checks upon the amount of water used for this purpose and will result in great economies.

If the present source of supply is to be continued, larger coagulating basins will be found to be necessary to secure proper color removal without the use of an excessive dose of aluminum sulphate. At least 12 hours' storage capacity should be provided. If, on the other hand, the Northwest Branch project is to be adopted in the near future, it is not deemed advisable at this time to enlarge the coagulating basins. Further study of the latter project will doubtless indicate that the basins have at present sufficient capacity for the treatment of that water.

The foregoing recommendations should be acted upon at once in the interest of the health of the community and are irrespective of any action that may be taken upon other projects. Whether deep wells or a new intake are to be investigated, the present plant requires this minimum of attention to safeguard the public health. It is believed that these steps are sufficient to properly safeguard health and that other considerations are merely matters of personal preference or possibly of economy. It must be admitted, however, that the objections to the present system even under its most efficient management are very real, and that if the people of Wilmington desire and can afford better water supply it is their right and privilege to be heard in this matter.

Of the various alternative projects that have been considered the extension of the intake on the Northwest Branch of the Cape Fear River is by far the most promising. It is recommended that the necessary engineering studies involving the cost of the East Branch siphon, the 2 miles of pipe line, and the low-lift pumping station be undertaken at once. There are no serious engineering problems involved here and the necessary engineering studies can be made without unreasonable expense. At the same time it is recommended that chemical and bacteriological studies of the water of the canal alluded to, be undertaken. These should be made with the object of determining the general chemical characteristics of the water and the possibilities of its chemical treatment; the hygienic characteristics of the water with special reference to determining whether or not any pollution from Wilmington reaches this point; and, finally, what saving in chemicals, sulphate of aluminum, soda ash, and chlorine would be indicated by the use of this water. If, as I anticipate, the saving in cost represents a very considerable part of the investment, the project would certainly seem to be one worthy of consideration. In any event, it is but proper to place before the citizens of Wilmington a definite statement of the advantages that are possible and the cost of obtaining those advantages over the present cost of water, in order that the final outcome may be decided after a full and frank discussion and upon an impartial presentation of all the facts in the case.

Acknowledgments.

The writer wishes, in conclusion, to express his grateful appreciation to Dr. W. S. Rankin, secretary, and to Mr. Warren H. Booker, engineer, of the State board of health, for valuable personal information and various reports, laboratory results, and other documentary material placed at his disposal; to the Hon. Parker Quince Moore, mayor of the city of Wilmington; to Martin S. Willard, chairman of the board of health, and to Councilman Wood and Supt. Merritt, city water department, for many courtesies extended and especially for opportunities offered to meet representative citizens of Wilmington; to Dr. Charles T. Nesbit, superintendent of health, for much valuable information carefully compiled for my study and also for having placed at my disposal the complete records of the board of health; and to George F. Catlett, city chemist and director of the laboratory, who has given me every possible assistance in arriving at a knowledge of the facts and whose personal efforts to simplify the duties involving upon me by the compilation of statistical data and analyses greatly reduced the labors of this investigation.

Consultations were had with Dr. W. S. Rankin, secretary of the State board of health, and with Mr. Warren H. Booker, engineer of the board; Hon. Parker Quince Moore, mayor of the city of Wilmington; Martin S. Willard and Charles T. Nesbit, M. D., chairman and superintendent, respectively, of the city and county boards of health; Councilman Wood; Supt. Merritt, of the water department; City Chemist Catlett; and with a number of citizens of Wilmington having special knowledge of, or interest in, the local water-supply question.

The following descriptive and statistical data have also been placed at my disposal and have been given careful study: Map of the city of Wilmington, prepared by Mr. H. DeW. Rapalje, consulting engineer; report on the examination of sanitary conditions at Wilmington, prepared by Warren H. Booker, June, 1911, embodying also reports of Messrs. Lucas, Humphries, and Rapalje on the sewerage system of Wilmington, and of George T. Hammond, consulting engineer of New York City, on the same subject; report on a waterborne epidemic of typhoid fever in Wilmington, prepared by Dr. W. S. Rankin, July, 1911; report of George C. Whipple on the water supply of Wilmington, dated December, 1911; chart prepared by Charles T. Nesbit, M. D., superintendent of health, showing the chronological incidence of typhoid fever in Wilmington during the months of June, July, and August, 1911, and the distribution of cases during this period with respect to water supply and milk supply; a further chart on file at the office of the board of health showing the geographical distribution of cases during this same period and statistical tables showing the racial distribution; report of George F. Catlett, director of the board of health laboratory, dated October, 1913, giving a detailed account of the present city water supply with a history of the various studies that have been made in connection with this supply, comparative statistics from other cities, and a full discussion of the events and conditions which made it seem necessary to advise the public on June 1, 1913, that the public water could not be safely used without boiling; a supplementary report by Mr. Catlett, dated November 29, 1913, giving a detailed summary of the monthly tests on the Wilmington water made by the State laboratory during the years of 1911, 1912, and 1913 to date, and monthly summaries of daily tests made at the city laboratory from March, 1912, to date on both the untreated river water and the filter effluent; some seventy analyses of deep wells in Wilmington made by the State board of health during the years of 1911, 1912, and 1913; fifty-six additional analyses made by George F. Catlett of deep-well water in and about Wilmington during the years 1912 and 1913, giving more complete information on the mineral constituents of these well waters; results of tests on river currents, report of Messrs. Hazlehurst and Anderson, under date of February 2, 1911; log of deep-well boring made for the Clarendon Water Works Co. at its pumping station on the east bank of the Cape Fear River in 1898, 1899, the log being the results of examinations at each 10-foot depth made by Mr. George H. Sweeney, chief engineer of the Wilmington waterworks; letters from J. A. Holmes, United States Bureau of Mines, formerly State geologist of North Carolina, dealing with the question of deep wells; letters from Joseph Hyde Pratt, Ph. D., State geologist of North Carolina, dealing with the same subject; report of the geological and economic survey, Volume III, 1912, on the Coastal Plain of North Carolina; report of Myron Fuller to the American Water Works Association, 1908, on the waters of the Atlantic Coastal Plain, and a memorandum submitted by Mr. A. N. Dubois, Wilmington, showing the results of the treatment of Cape Fear River waters by a special process, the details of which are not shown.